Enabling High Volume Manufacturing of Double Patterning Immersion Lithography with the XLR 600ix ArF Light Source

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Deep ultraviolet (DUV) lithography improvements have been focused on two paths: further increases in the effective numerical aperture (NA) beyond 1.3, and double patterning (DP). High-index solutions for increasing the effective NA have not gained significant momentum due to several technical factors, and have been eclipsed by an aggressive push to make DP a high-volume manufacturing solution. The challenge is to develop a cost-effective solution using a process that effectively doubles the lithography steps required for critical layers, while achieving a higher degree of overlay performance. As a result, the light source requirements for DP fall into 3 main categories: (a) higher power to enable higher throughput on the scanner, (b) lower operating costs to offset the increased number of process steps, and (c) high stability of optical parameters to support more stringent process requirements. The XLR 600i (6kHz, 90W @15mJ) was introduced last year to enable DP by leveraging the higher performance and lower operating costs of the ring architecture XLR 500i (6kHz, 60W @10mJ) platform currently used for 45nm immersion lithography in production around the world. In February 2009, the XLR 600ix was introduced as a 60/90W switchable product to provide flexibility in the transition to higher power requirements as scanner capabilities are enhanced. The XLR 600ix includes improved optics materials to meet reliability requirements while operating at higher internal fluences. In this paper we will illustrate the performance characteristics during extended testing. Examples of performance include polarization stability, divergence and pointing stability, which enable consistent pupil fill under extreme illumination conditions, as well as overall thermal stability which maintains constant beam performance under large changes in laser operating modes. Furthermore, the unique beam uniformity characteristics that the ring architecture generates result in lower peak energy densities that are comparable to those of a typical 60W excimer laser. In combination with the XLR's long pulse duration, this allows for long life scanner optics while operating at 15mJ.

Energy stability

In addition to higher output power, double patterning applications impose strict requirements on the quality of light at the laser output. Energy stability is one of the critical performance parameters that must be addressed to ensure delivery of exact dose while meeting scanner high throughput requirements. This translates to improvements in on-wafer CD uniformity while enabling higher throughput. To satisfy this need energy stability of XLR 600ix system is significantly improved with respect to previous generation of XLR systems. Additional laser control system changes ensure consistent

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and reliable energy stability performance under all operating conditions of XLR 600ix. In Figure 1 we present dose stability performance typically demonstrated by XLR 600ix systems during a stress test. This stress test consists of varying laser repetition rates from 1.5 to 6kHz, duty cycle from 10 to 75%, and energy ±15% around target. This type of test exercises the capabilities of the laser up to the extremes of performance requirements and is used to identify potential weaknesses. Dose in the example here is measured using a 30-pulse window, and this laser is able to achieve <0.1% variation. Such demonstrated dose stability is unprecedented and contributes to further improvements in CD uniformity.

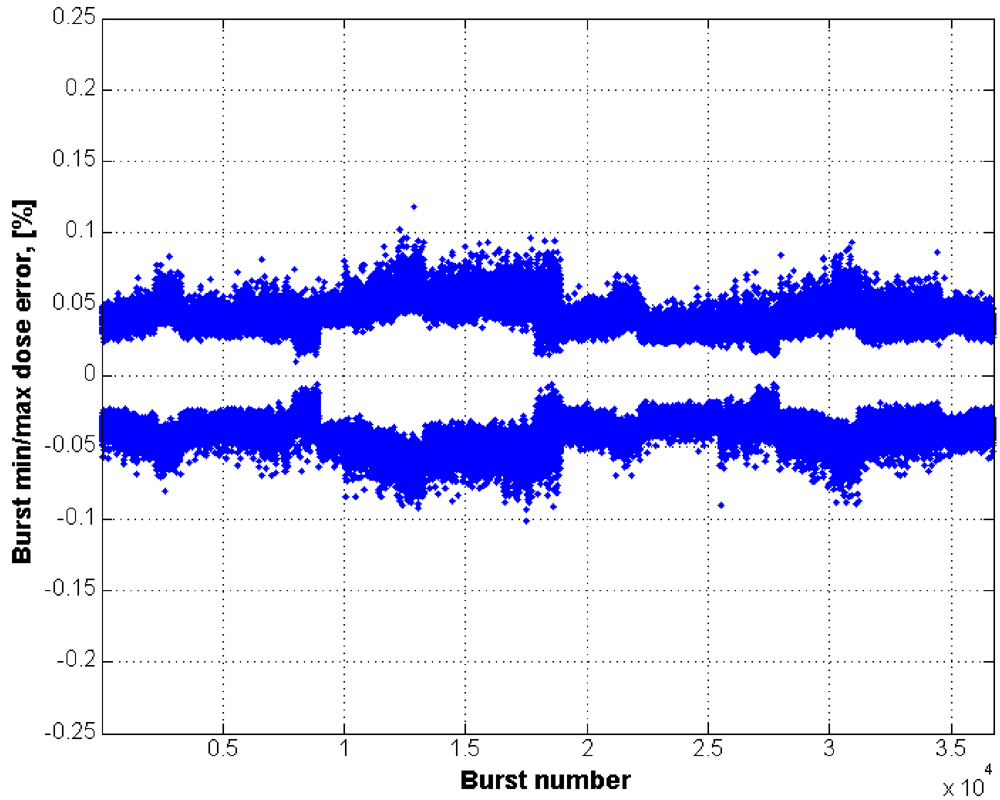

Figure 1: Dose stability of XLR 600ix system during 15M pulse stress test, exercising full range of pulse repetition rates, energy targets and duty cycles. The graph represents minimum and maximum deviation of the dose for all bursts fired during the test

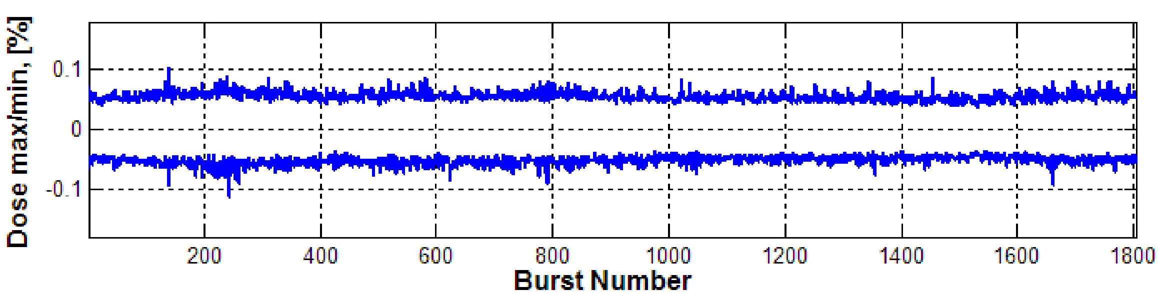

Figure 2. Dose stability measured across a varying repetition rate from 1500 to 6000Hz.

In a different test, consisting of the firing patterns representing typical exposure mode operation, XLR 600ix systems demonstrate excellent dose stability over a wide range of repetition rates (Fig. 2).
In addition to the intrinsically more stable architecture that results from a ring configuration in the XLR, a sophisticated energy and timing control algorithm has been developed to achieve rapid, closed-loop control that mitigates the effects of transient behaviors when the laser is being modulated at different repetition rates and duty cycles. Figure 3 illustrates consistent energy and dose stability performance across five lasers where the maxima and minima are plotted from a test that includes duty cycle variations.

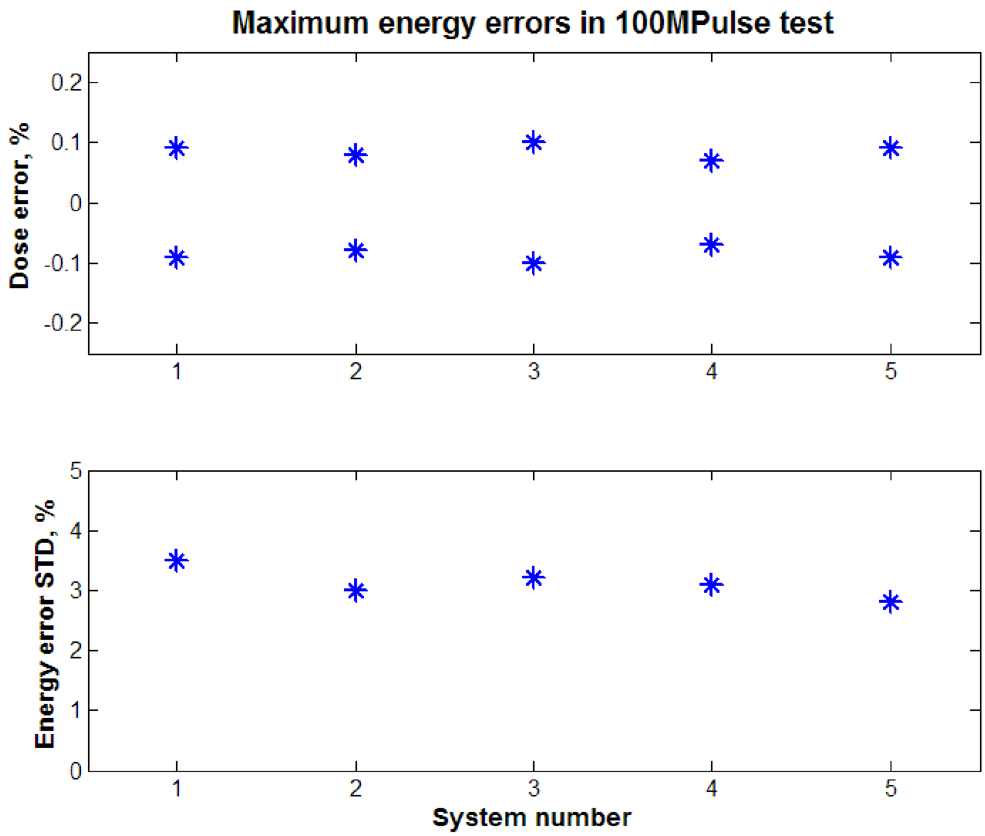

Figure 3: Energy stability of multiple XLR 600ix systems during 100 MPulse test with typical exposure mode firing patterns. Stars represent absolute maxima and minima of the full 100 MPulse test

Bandwidth E95 stability and tuning

In addition to improved dose stability that resulted from an advanced energy and timing control system in the XLR 600ix, an improvement in bandwidth stability has also been realized. Bandwidth variations are typically caused by laser discharge chamber acoustic resonances coincident with particular repetition rates. As a laser is exercised across such resonances in typical operation, a fast closed-loop controller compensates for these variations and dampens these effects to a minimum, thus achieving very stable bandwidth

for consistent within-die and within wafer exposures. Figure 4 shows E95 bandwidth data during the same test that created the dose stability data in Figure 2.

One of the key features of XLR 600ix is its ability to operate at various degrees of spectral bandwidth, allowing precise tuning of semiconductor manufacturing process for various applications. In some applications even stable tuning of burst-burst bandwidth E95 is required and the XLR 600ix can meet these requirements while maintaining excellent stability of the output beam parameters. In the Figure 5, we demonstrate bandwidth E95 stability achievable by XLR 600ix systems during a stress test, exercising full range of system energy targets and pulse repetition rates while meeting all performance specifications without any reservations.

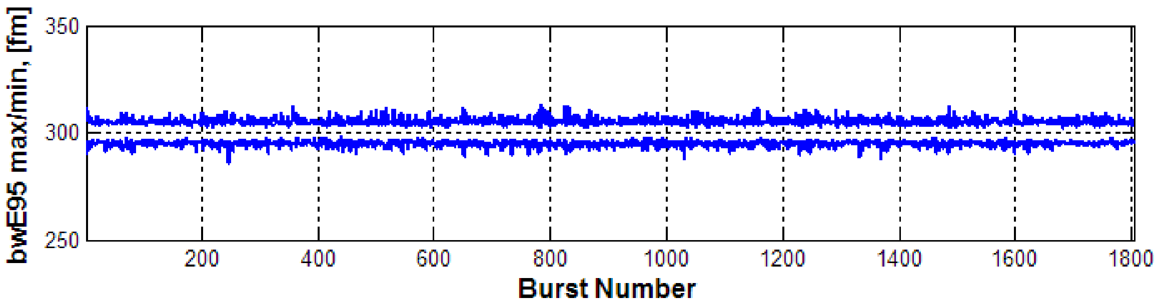

Figure 4. E95 Bandwidth stability measured across a varying repetition rate from 1500 to 6000Hz. Data was collected at the same time as that shown in Figure 2.

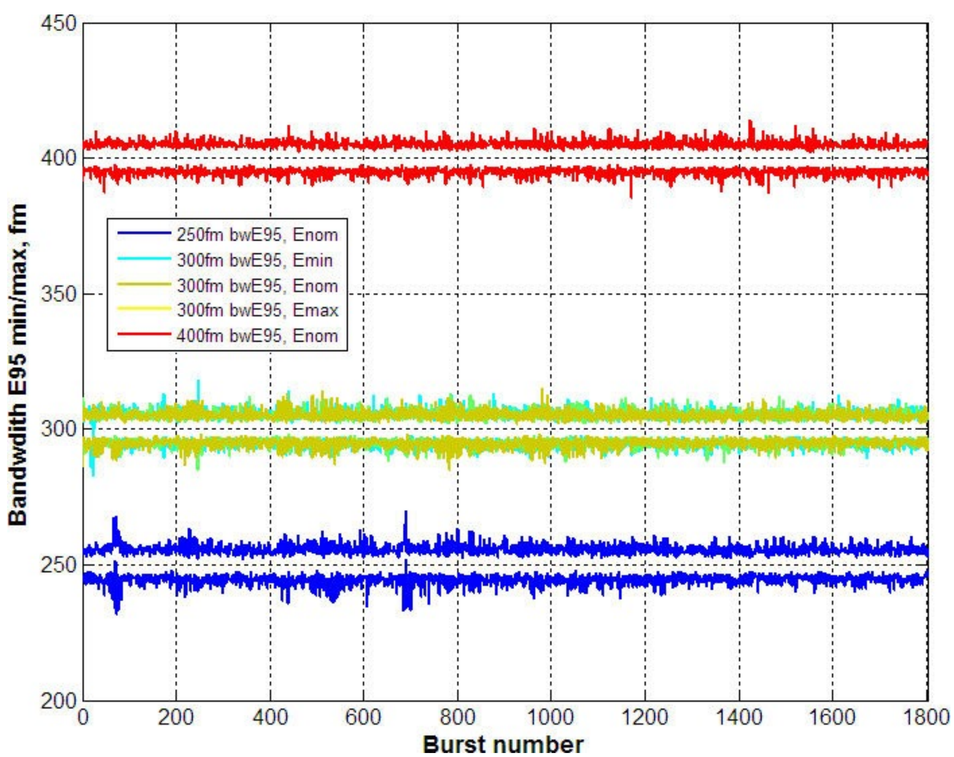

Figure 5: Bandwidth E95 stability during stress test at various bandwidth E95 targets, energy targets and pulse repetition rates.

In this test, three different bandwidth targets are selected, 0.25pm, 0.30pm and 0.40pm, and the plots show the maxima and minima of each burst at the nominal 15mJ energy target. In addition, high and low energy targets are also used during the test at 0.30pm bandwidth; the data are difficult to distinguish from each other due to the every consistent performance across these test.

The ability to modulate E95 bandwidth 'on the fly' is demonstrated in Figure 6, where the laser is commanded to switch to different bandwidth targets from one burst (equivalent to one die exposed) to the next. This fast burst-burst bandwidth tuning of the XLR 600ix opens the new area for semiconductor manufacturing applications, allowing fast and reliable tuning of the manufacturing process to the exact needs of the user, such as in optical proximity correction (OPC) optimization.

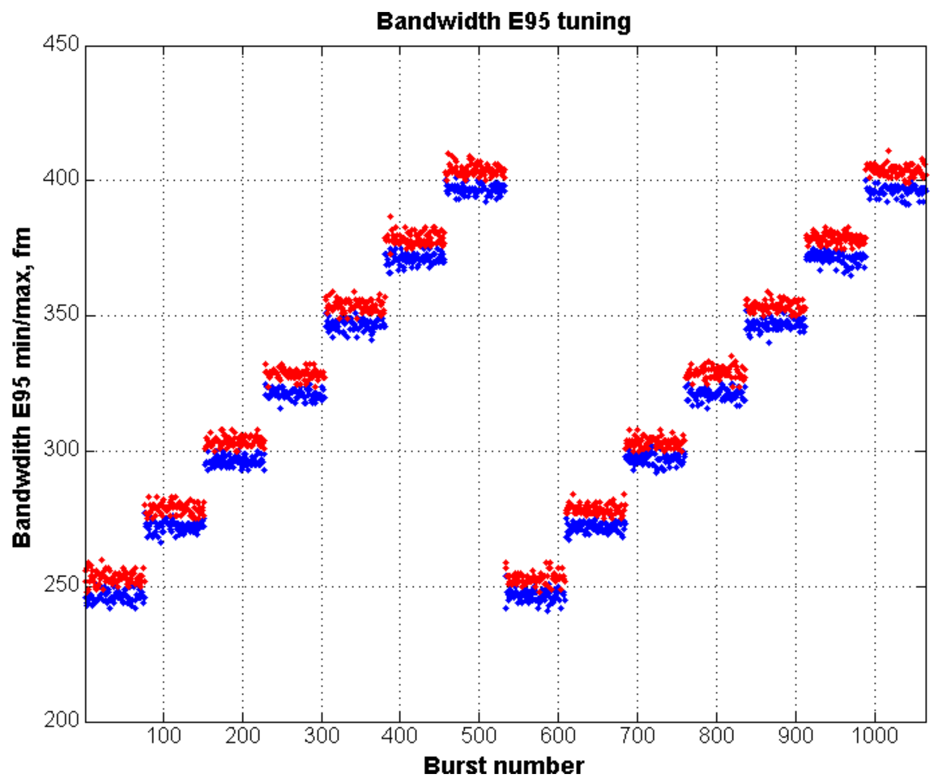

Figure 6: Burst-burst bandwidth E95 tuning performance showing very high bandwidth stability (minimum value: blue, maximum value: red) while the laser is commanded to step to different bandwidth targets (250, 275, 300, 325, 350, 375 and 400fm).

Wavelength stability

Wavelength stability plays a role in achieving good contrast, focus and OPC. A new wavelength controller has been developed for the XLR 600ix that further improves stability through a more sophisticated and fast closed-loop function. Figure 7 illustrates this performance with data that was collected at the same time as those shown for dose and bandwidth stability (Figs. 2 and 4).

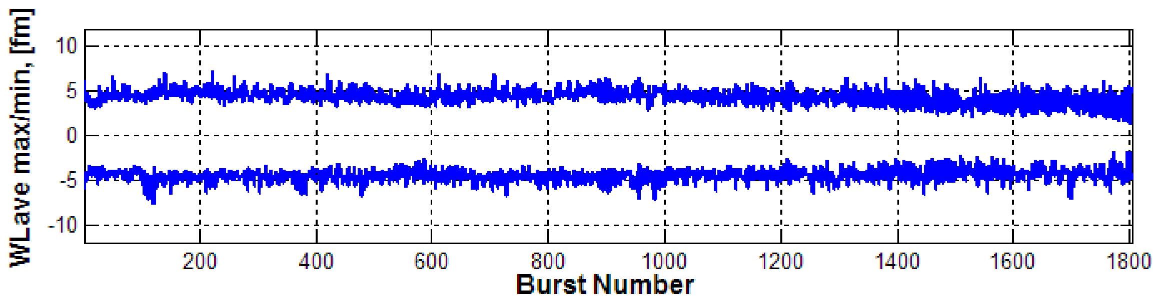

Figure 7. Min/max error in average wavelength measured across a varying repetition rate from 1500 to 6000Hz. Data was collected at the same time as that shown in Figs. 2 and 4.

Beam parameter stability

Operating a laser system at 90W output power leads to large variations of thermal conditions and significantly varying thermal stress on all components of XLR 600ix. In general, power load on the optical components can lead to variation of system performance in terms of the beam divergence, pointing, near-field profile and polarization stability. Multiple design decisions were made to address high optical power load and ensure stable beam parameter operation at all energy targets and duty cycles. In Figure 8 we show beam divergence and pointing stability, demonstrated on the XLR 600ix during a stress test, exercising full range of pulse repetition rates and energy targets while operating at high duty cycle.

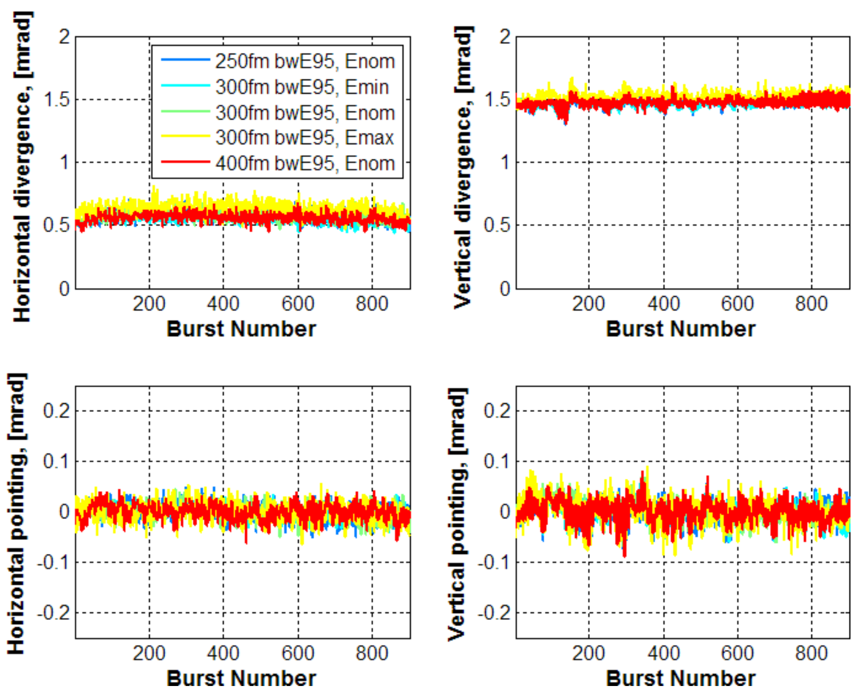

Figure 8: Beam divergence and pointing stability during stress test, exercising full range of pulse repetition rates, energy and bandwidth E95 targets of XLR 600ix operating at high duty cycle.

In this test, pulse repetition rates are modulated between 1500 and 6000Hz. The tests are repeated at 3 different bandwidth targets, and 3 energy settings (15mJ ±15%), similar to the conditions used to generate data in Fig. 5. The results show an extremely stable set of beam properties, demonstrating the robustness of this architecture.

One of the concerns that scanner lens makers have with increased optical power is potential damage to the lens system due to high peak irradiance of the laser output beam. XLR 600ix systems typically demonstrate 130ns or longer total integral squared (TIS) pulse duration while maintaining low peak energy density, well below the 35 mJ/cm^2 limit required by scanner optics. Low peak energy density is achieved consistently at all duty cycles of XLR 600ix systems as shown in Figure 9. During this test system maintains excellent quality of the near field beam profile, ensuring uniform filling of the output aperture of the laser system.

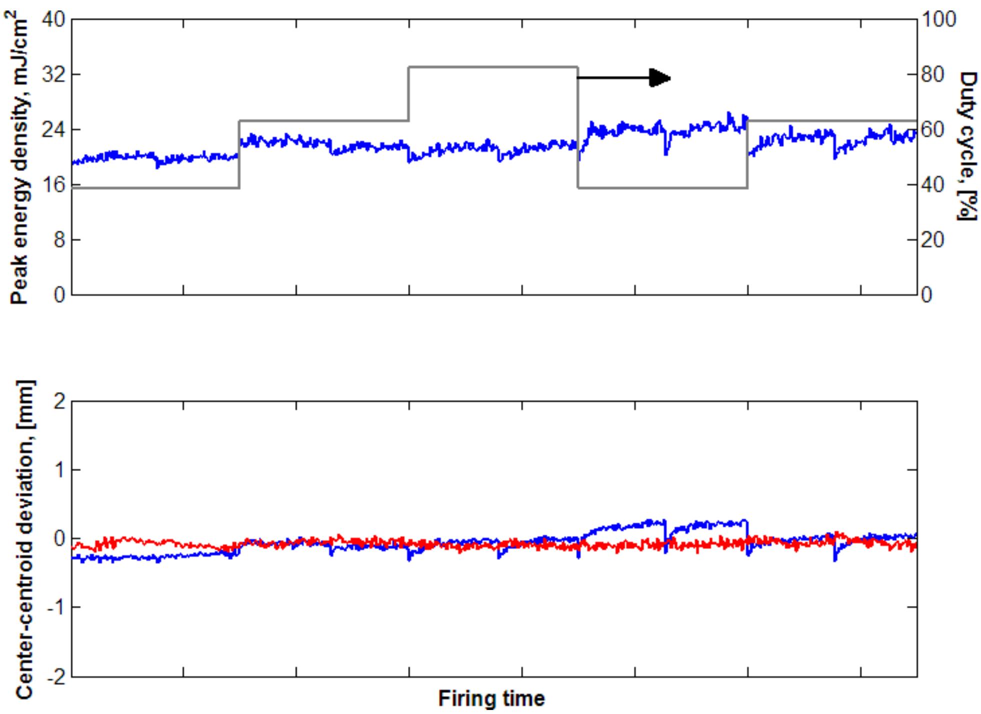

Figure 9: Peak energy density and beam parameter stability at medium and high duty cycles

Polarization Ratio

Polarization ratio of the laser output can be significantly degraded by high power operation due to thermally induced birefringence in the optical components of the laser system. Key improvements made to the optical components of the ring architecture significantly reduce potential risk of polarization loss under high fluence levels resulting in excellent polarization stability demonstrated by XLR 600ix systems operating at high duty cycle as shown in Figure 10.

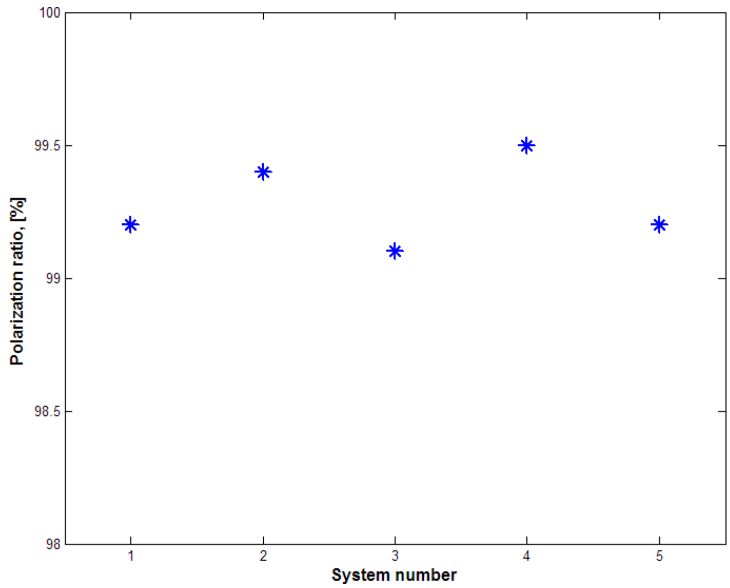

Figure 10: Minimum output polarization ratio of multiple XLR 600ix systems operating at 75% duty cycle. Polarization ratio is defined as (H-V)/(H+V).

Summary

Introduction of the XLR 600ix light source meets demanding requirements of current DUV lithography applications with the extendibility built-in to enable higher power needs. Based on the proven ring technology architecture, the XLR 600ix consistently delivers excellent performance while maintaining low operating cost. Advances introduced for high throughput, high stability requirements are realized in the areas of output energy, bandwidth and wavelength. The XLR 600ix also offers precise bandwidth tuning of the light source to address the needs of advanced semiconductor manufacturing, covering a wide range of lithography applications. Furthermore advanced gas management technology (GLX), employed on XLR 600ix systems when combined with improvements to key system modules ensures long module life and low operation cost.